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HST/WFPC2 observations of the core of KjPn 8

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Abstract. Narrow-band images of the core of the extraordinary poly-polar planetary nebula KjPn 8 have been obtained with the WFPC2 camera on board the Hubble Space Telescope. Spasmodic bipolar ejections, in changing directions have occurred over thousands of years to create KjPn 8. The central star is finally revealed in these observations and its compact nebular core is resolved into a remarkably young ≈ 500 years old, elliptical ionized ring. The highest speed bipolar outflows are perpendicular to this central ring which is identified as the latest event in the creation of this nebula. The formation history of KjPn 8 has involved two distinct planetary nebula-like events, probably originating from a binary core evolution with components of similar mass.

1. Introduction

The extraordinary nature of the poly-polar planetary nebula, KjPn 8, has become apparent during a series of ground–based observations (López, Vázquez,

& Rodríguez 1995; López et al. 1997, López et al. 1999; Steffen & López 1998; Vázquez, Kingsburgh, & López 1998). A distance estimation to KjPn 8 of 1600 $\pm$ 230 pc, has been deduced by a combination of proper motion and kinematical measurements (Meaburn 1997). It is the $14' \times 4'$ extent of the largest lobes, with knots C_1–C_2 at their extremities as shown in Fig. 1a, compared with the few arcsec diameter of the bright nebular core, that first indicated the unusual nature of this nebula. Also, secondary, smaller lobes, delineated by knots A_1–A_2 in Figure 1 (top), have a distinctly different axis from C_1–C_2.

The recognition of multiple outflows along different axes lead originally to their interpretation as the action of a bipolar, rotating, episodic jet or BRET (López et al. 1995).

However, it has required optical imagery with the Hubble Space Telescope, to reveal the elliptical ionized ring which constitutes the nebular core of KjPn 8 and to locate the central star which is now shown to be at the center of this ionized central ring. This ring is clearly the ionized, inside surface of a 7 arcsec diameter ring of excited H_2 (López et al. 1999), see Figure 1 (bottom), itself located within a central 30 arcsec diameter CO disk (Foreveille et al. 1998) whose axis is aligned with the bipolar outflows defined by A_1–A_2 in Figure 1 (top).

2. Dynamical characteristics

The largest lobes, with knots C_1–C_2 at their extremities, from their linear dimensions (6.5 $\times$ 1.9 pc) and kinematics, must be $1 - 2 \times 10^4$ yr old (Steffen & López 1998), whereas the knots, A_1–A_2, aligned with the axis of the ring have a kinematical age $\leq 3,400$ yr as given directly by their angular displacements from the nebular core combined with measurements of their expansion proper motions (Meaburn 1997). This particular timescale estimation is independent of the distance to KjPn 8. The ionized ring itself, if expanding at a constant 40 km s^{-1}, would only take $\sim$ 500 yr to reach its present 2.7 arcsec ($\equiv$ 0.02 pc) radius.

These temporal differences indicate that the A_1–A_2 high-velocity (320 km s^{-1}) knots and associated bipolar outflows were formed prior to the present central ionized ring. Furthermore, the largest features, culminating in the knots C_1–C_2, must have formed along a different ejection axis well before any of the central ionized and molecular circumstellar structures had been formed.

The small dimensions of the central ionized ring, associated molecular material and low excitation nebular spectrum (Vázquez et al. 1998), indicate that the physical characteristics of the core of KjPn 8 are representative of a very young PN. Moreover, its ionic abundances, with enhanced He and N, (Vázquez et al. 1998) correspond to extreme type I PNe that are identified with massive ($> 2.4 M_\odot$) progenitors (Peimbert & Torres-Peimbert 1994) which should evolve relatively quickly during the PN stage towards higher effective temperatures and consequently higher excitation conditions. This implies that the core of KjPn 8 has only reached photoionization conditions during the last few hundred years and the formation of the bipolar high-speed (A_1–A_2) outflows ocurred shortly before, during the pre-planetary nebula stage.

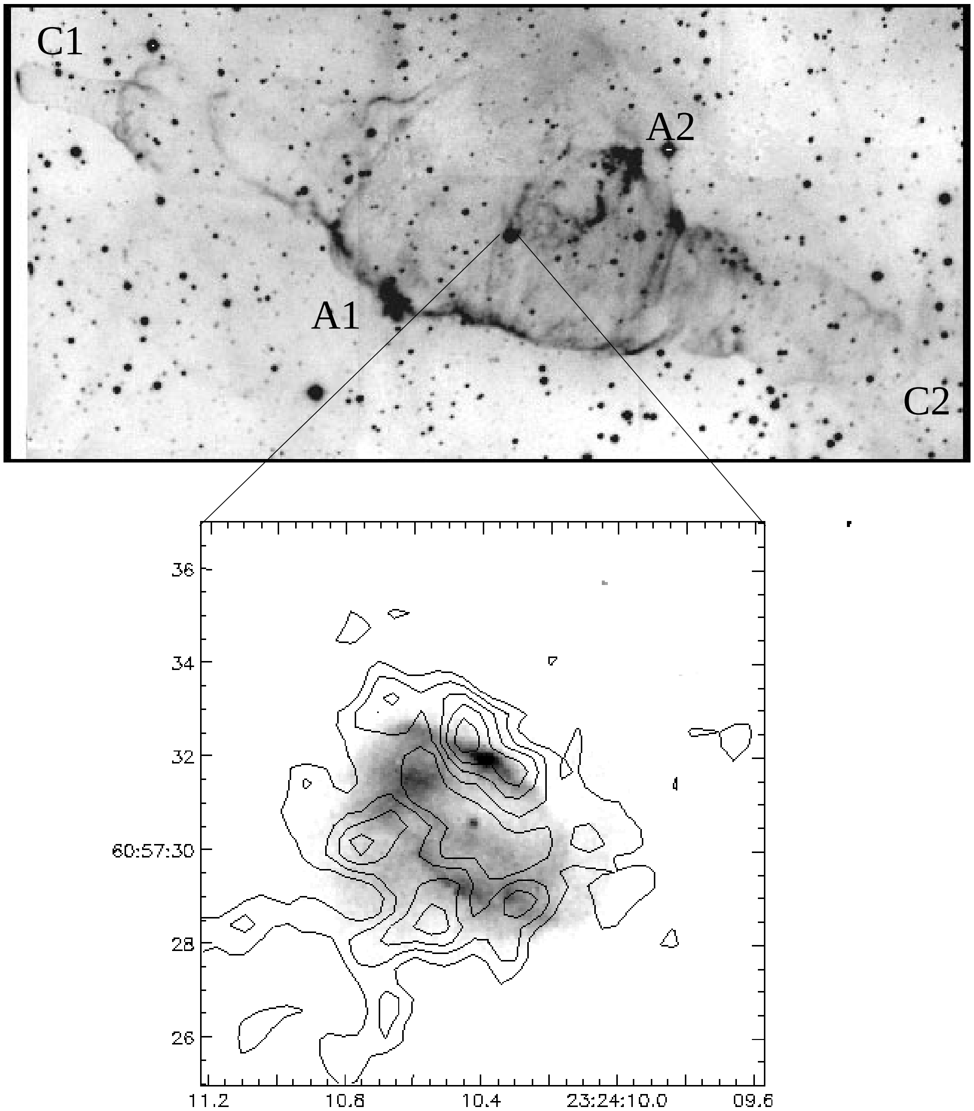

Figure 1. Top- A deep Hα wide field, ground-based, image of the polypolar nebula KjPn 8. The symmetric knots C_1–C_2 (PA 72°) and A_1–A_2 (PA 126°) are located at the tips of independent bipolar outflows. The whole nebula is $14' \times 4'$ in extent. Bottom- A contour map of excited H_2 $v = 1 \rightarrow 0$ S(1) at 2.122 μm is shown overlayed on the [S II] HST image of the core of KjPn 8 where the central star is apparent. The H_2 emission surrounds and shares the morphology and orientation of the ionized ring, as also does a larger disk of CO (Forveille et al. 1998) not shown here, confirming a second heavy mass-loss episode in KjPn 8.

For the current core conditions, the associated CO and H_2 molecular material must be related to a second heavy mass-loss episode prior to the formation of the ionized nebular core. The disk-like structure and common orientations of the molecular material and ionized nebular ring confirm their connection in this second event. These characteristics are incompatible with the expected conditions that the core must have had at the time when the C_1–C_2 bipolar outflows where triggered. The arguments lead to the conclusion that the formation of the giant bipolar envelope had its origin in a different event, unrelated to the creation of the present nebular core and associated bipolar outflows.

KjPn 8 thus unfolds a unique situation among PNe: the creation of a double planetary nebulae event. A large bi-conical nebula was formed through episodic jets (Steffen & López 1997) along PA 72° (C_1-C_2), 1 - 2 $\times 10^4$ years ago. These jets have now ceased their activity. A second planetary nebula event is initiated $\leq 3,400$ years ago ejecting high-velocity bipolar outflows along PA 126° (A_1-A_2). Unequivocal signatures of a second heavy mass-loss, superwind episode accompany this second event. Massive molecular disks of CO and H_2 surround now a very young ionized ring, all of which are perpendicular to the most recent A_1-A_2 bipolar outflows.

A possible explanation for the formation of KjPn 8 is that here we are witnessing the near-simultaneous death of two relatively massive stars in a binary system either with a separation large enough for no effective mass transfer to take place (separations from several tens to a few hundred astronomical units) or detached binaries (with separations of the order of a few tens of AU) where the evolution of an originally less massive secondary may be speeded up by wind accretion from the primary so both reach the PN stage one shortly after the other, within 1-2 $\times 10^4$ years. Two PNe-type events have thus been consecutively produced from a binary core where the influence of the companion has probably aided in the production of bipolar outflows on each occasion and for each event having its own symmetry axis. Full details of this work will appear elsewhere.

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